intel®

Ultra Low Voltage Intel® Celeron® Processor in the Micro FC-BGA Package

Thermal Design Guide

October 2002

Order Number: 273802-001

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Revision History

Date	Revision	Description
October 2002	1.0	Initial Release

1.0 Introduction

This document describes the thermal design guidelines for the Ultra-Low Voltage Intel® Celeron® processor in the surface mount, 479-pin, micro FC-BGA package. Detailed mechanical and thermal specifications for this processor can be found in the *Ultra-Low Voltage Intel® Celeron® Processor (0.13 µ) Datasheet*.

The information provided in this document is for reference only and additional validation must be performed prior to implementing the thermal solution designs into final production. The intent of this document is to assist customers with the development of thermal solutions for their individual designs. The final thermal solutions, including the heat sink, attachment method, and thermal interface material (TIM) must comply with the mechanical design, environmental, and reliability requirements specified in the processor datasheet. It is the responsibility of the OEM to validate the thermal solution design with their specific applications.

1.1 Document Goals

The goal of this document is to describe the thermal characteristics for the Ultra-Low Voltage Intel® Celeron® processor and provide guidelines for meeting the thermal requirements for single and dual processor systems. The thermal solutions presented in this document are specifically designed for embedded applications, including the Compact PCI* form factors.

1.2 Document Scope

This document discusses the thermal management techniques for the Ultra-Low Voltage Intel® Celeron® Processor (0.13 µ), specifically in embedded computing applications. The physical dimensions and power values used in this document are for reference only. Refer to the processor's datasheet for the most up-to-date information. In the event of conflict, the data in the datasheet supercedes any data in this document.

1.3 References

- *Ultra-Low Voltage (LV) Celeron® Processor (0.13 µ) Datasheet* (Document # 273804)
- *Low Voltage Intel® Pentium® III Processor 512K Dual Processor Platform Design Guide* (Document # 273674)
- *Mobile Pentium® III Processor-M Datasheet* (Document #2 98340)
- *Intel® Mobile Processor Micro-FCPGA Socket Design Guidelines* (Document # 298520)
- *Intel® Pentium® III Processor Thermal Design Guidelines* (Document # 245087)
- *Thermal Design Guide for Intel® Processors in the BGA2 and Micro FC-BGA Packages for Embedded Applications* (Document # 273716)

1.4 Definition of Terms

Term	Definition
Δ	Delta - difference, or change between two states
θ_{CA}	The thermal resistance between the processor's case and the ambient air. This is defined and controlled by the system thermal solution
θ_{CS}	The case to sink thermal resistance, which is dependent on the thermal interface material. Also referred to as θ_{TIM}.
θ max	Maximum allowable thermal resistance
BGA	Ball grid array
° C	Degrees in Celsius
CFD	Computational fluid dynamics
CFM	Airflow rate in cubic feet per minute
DP	Dual processing capability
in.	Inches
LFM	Airflow velocity in linear feet per minute
LV	Low Voltage
PCB	Printed circuit board
T_{case}	The measured case temperature of the processor
$T_{case\text{-}max}$	The maximum case temperature of the processor, as specified in the processor datasheet
T_{LA}	$T_{Local\text{-}Ambient}$ – the measured ambient temperature locally surrounding the processor. The ambient temperature should be measured approximately 1 inch upstream from the passive heat sink.
TDP	Thermal Design Power (TDP) – A specification of the processor. OEM's must design thermal solutions that meet or exceed the TDP as specified by the processor's data sheet.
TIM	Thermal Interface Material – the thermally conductive compound between the heatsink and processor case. This material fills air gaps and voids, and enhances spreading of the heat from the case to the heatsink.
U	A unit of measure used to define server rack spacing height. 1U is equal to 1.75 inches, 2U equals 3.50 inches, etc.
ULV	Ultra Low Voltage
W	Watt

2.0 Design Guideline

The thermal solutions presented in this document were designed to fit within the maximum component height allowed by the Compact PCI* specification. The heat sink designs were optimized for the Compact PCI* form factor and with airflow equivalent to 200 LFM at one inch upstream of the processor. In addition, the Ultra-Low Voltage Intel Celeron 400 MHz Processor (0.13 µ) is suitable for natural convection cooling with a properly designed heat sink. This document includes guidelines for using natural convection cooling techniques with the Celeron 400 MHz Processor (0.13 µ). The thermal solutions may be valid for other form factors, however individual applications must be modeled, prototyped, and verified.

Prototype parts have been fabricated for verification tests. It is important to note that the thermal verification tests described in this document are not adequate for statistical purposes. The intent of testing was only to verify that the thermal components were performing within reasonable expectations, based on computer modeling and component specifications.

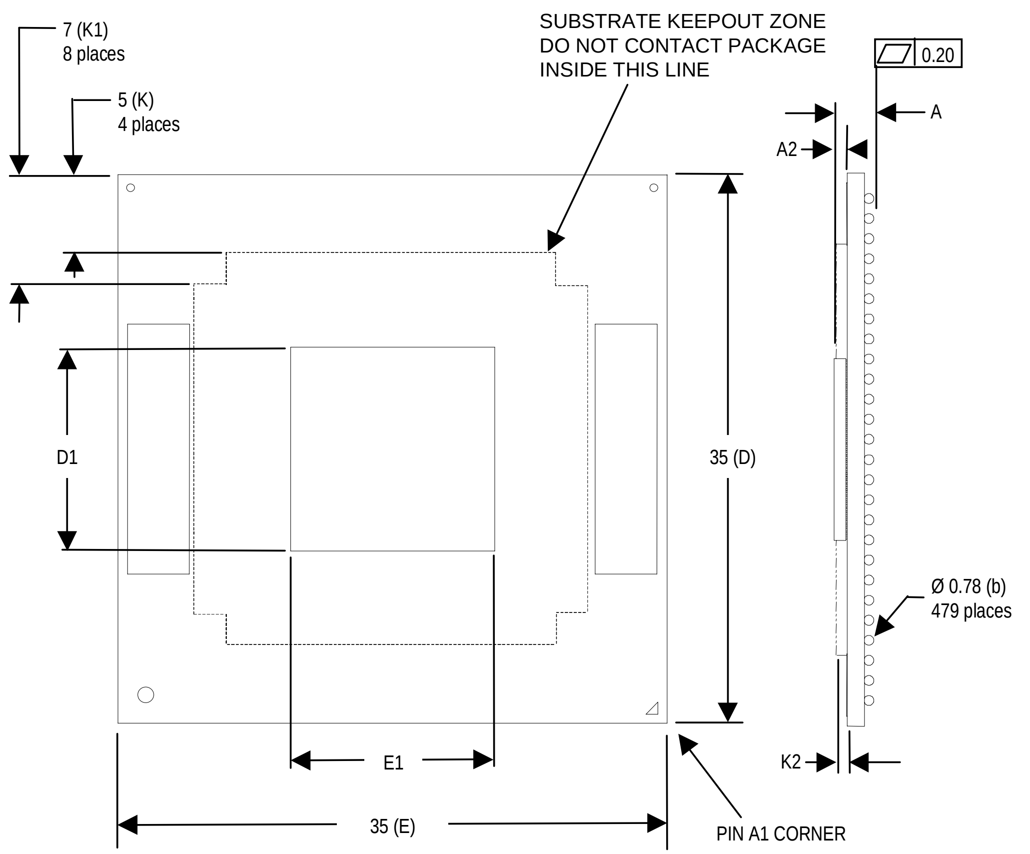
2.1 Technical Guidelines

2.1.1 Processor Package

In order to maintain compatibility with the micro-FCPGA package, it is recommended that the specification for the keep out zone, and mounting hole pattern as described in the *Intel® Mobile Processor Micro-FCPGA Socket Design Guidelines* be adhered to. The keep out zone and mounting hole pattern suggested in this document are intended to follow the guidelines specified in the aforementioned document. However, to accommodate an existing heat sink attachment fastener, the diameter of the mounting holes is different in this specification.

Figure 1 illustrates the geometry of the micro-FBGA package with dimensions provided in Table 1. Refer to the processor data sheet for detailed information.

Figure 1. Micro-FCBGA Package Geometry



NOTE: All dimensions in millimeters. Values shown are for reference only. See Table 1 for specific details.

Table 1. Micro-FCBGA Mechanical Specifications

Symbol	Parameter	Min	Max	Unit
A	Overall height, as delivered[1]	2.27	2.77	mm
A2	Die height	0.854		mm
b	Ball diameter	0.78		mm
D	Package substrate length	34.9	35.1	mm
E	Package substrate width	34.9	35.1	mm
D1	Die length	11.18[3] 10.82[4]		mm
E1	Die width	7.20[3] 6.85[4]		mm
e	Ball pitch	1.27		mm
N	Ball count	479		each
K	Keep-out outline from edge of package	5		mm

Table 1. Micro-FCBGA Mechanical Specifications

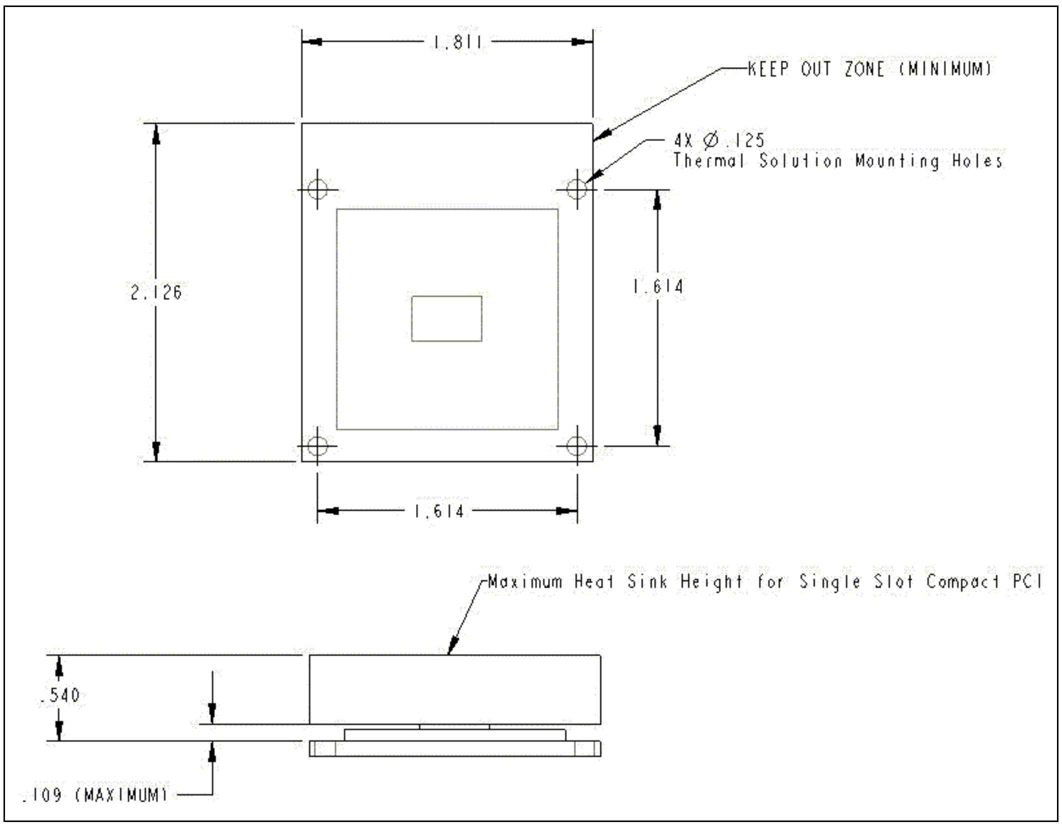
K1	Keep-out outline at corner of package	7		mm
K2	Capacitor keep-out height	-	0.7	mm
S	Package edge to first ball center	1.625		mm
--	Solder ball coplanarity	0.2		mm
Pdie	Allowable pressure on the die for thermal solution	-	689	kPa
W	Package weight	4.5		g

NOTES:
1. All dimensions are subject to change.
2. Overall height as delivered. Values were based on design specifications and tolerances. Final height after surface mount depends on OEM motherboard design and SMT process.
3. Dimension for CPUID = 0x06B1.
4. Dimension for CPUID = 0x06B4.

2.1.2 Keep In/Out Zones and Mounting Holes

The keep in zone reserved for the processor package, heat sink, and heat sink attachment method for the baseboard is shown in Figure 2. This is the typical keep out zone for the Micro-FCPGA package with the exception of the mounting hole diameter. The recommended mounting hole diameter has been increased from 0.09 to 0.125 inches. This allows the use of a readily available and proven mounting fastener. Refer to *the Ultra-Low Voltage (LV) Celeron® Processor (0.13 µ) 512K Datasheet* (Order #273673) for detailed information

Figure 2. Keep In Zone for the Micro-BGA Package, Primary Side



2.2 Thermal Guidelines

This document presents thermal solutions for the Ultra-Low Voltage Celeron® Processor (0.13 μ) in the Micro FC-BGA package. The required performance of the thermal solution is dependent on many parameters including the processor's thermal design power (TDP), maximum junction temperature (Tj max), the operating ambient temperature, and system airflow. The guidelines and recommendations presented in this document are based on specific parameters. It is the responsibility of each product design team to verify that thermal solutions are suitable for their specific use.

The thermal metrology for this processor should be followed to evaluate the thermal performance of proposed cooling solutions. The thermal metrology is contained in the *Intel® Pentium® III Processor Thermal Design Guidelines* (Document # 245087).

Thermal data for the processor is presented in Table 2. The data is provided for informational purposes only and is subject to change. Refer to the processor's datasheet for the most up-to-date data.

Table 2. Ultra-Low Voltage Intel® Celeron® Processor (0.13 μ) in the Micro FC-BGA Package Thermal Data

Core Frequency (MHz)	Typical Power (W)	Maximum Power (W)	Minimum T junction (º C)	Maximum T junction (º C)
400	3.40	4.23	0	100
650	7.00	8.30	0	100

2.2.1 Processor Junction Temperature

The processor's bare die is exposed in the FC-BGA package, which provides the common interface and attachment location for all processor thermal solutions. Techniques for measuring the junction temperature are provided in Section 7.3 of the *Intel® Pentium® III Processor Thermal Design Guidelines* (Document # 245087). The limits for the junction temperature can be found in the processors datasheet.

2.2.2 Processor Power

The processor's power specifications are documented by the maximum thermal design power, or TDP_{MAX}. Maximum power can be approached by running code specifically written to draw the most current, such as a maximum power test application. The most up-to-date TDP values can be found in the processors datasheet.

2.2.3 Thermal Solution Requirements

The thermal solutions recommended in this document were designed based on the processor thermal specifications as outlined in the processor's datasheet for the worst-case conditions. In addition, the operating ambient temperature was specified as 50° C with minimum system airflow of 200 LFM. The ambient temperature and airflow are based on a measurement approximately 1 inch upstream from the processor.

The thermal performance requirement for the heat sink is determined by calculating the junction-to-ambient thermal resistance, θ_{ja}. This is a basic thermal engineering parameter that can be used to evaluate and compare different thermal solutions and assess if a solution is suitable for a given application. For the ULV Celeron 650 MHz processor, the required θ_{ja} is calculated as shown in Equation 1. The required heat sink thermal performance for the ULV 400 MHz processor is shown in Equation 2.

Equation 1. Junction-to-Ambient Thermal Resistance for the ULV 650 MHz Processor

$$\frac{T_{j\ max}{}^{\circ}C - T_a{}^{\circ}C}{TDP_{max}(W)} = \frac{100^{\circ}C - 50^{\circ}C}{8.3W} = 6.02\frac{^{\circ}C}{W}$$

Equation 2. Junction-to-Ambient Thermal Resistance for the ULV 400 MHz Processor

$$\theta_{max} = \frac{T_{j\ max}{}^{\circ}C - T_a{}^{\circ}C}{TDP_{max}(W)} = \frac{100^{\circ}C - 50^{\circ}C}{4.23W} = 11.82\frac{^{\circ}C}{W}$$

Figure 3 and Figure 4 further illustrate the required thermal performance for the processors at different operating ambient temperatures. The thermal solutions used to cool the processor must have a junction-to-ambient thermal resistance less than or equal to the value shown for the given ambient temperature.

Figure 3. Thermal Resistances for Various Operating Temperatures (650 MHz Processor)

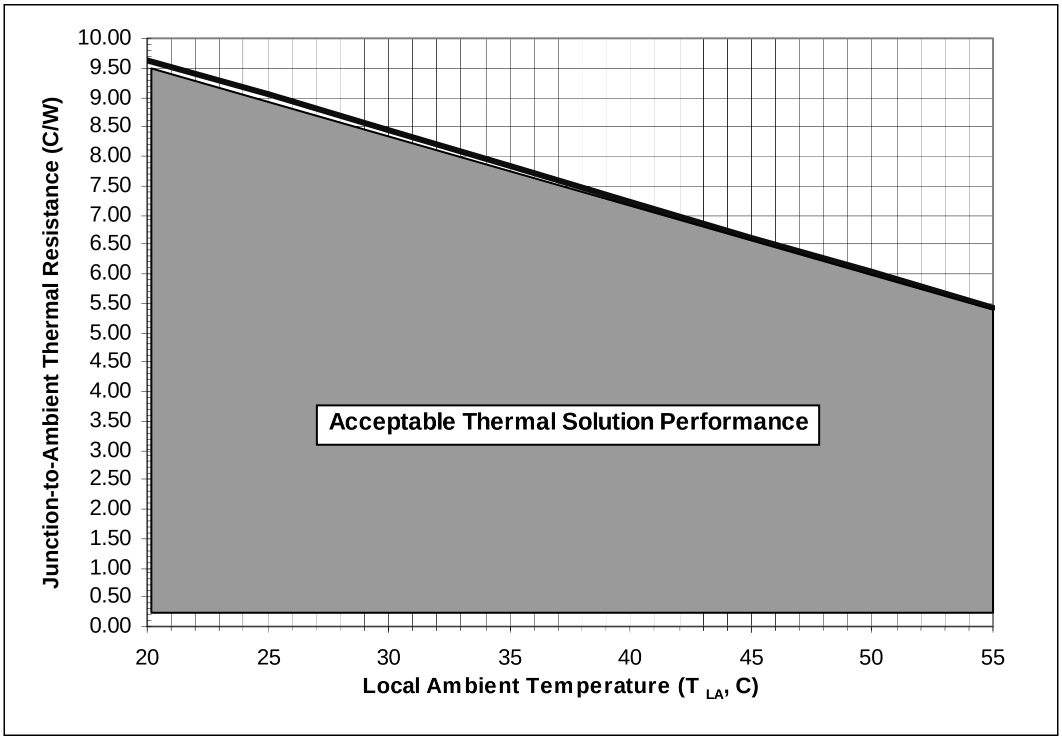
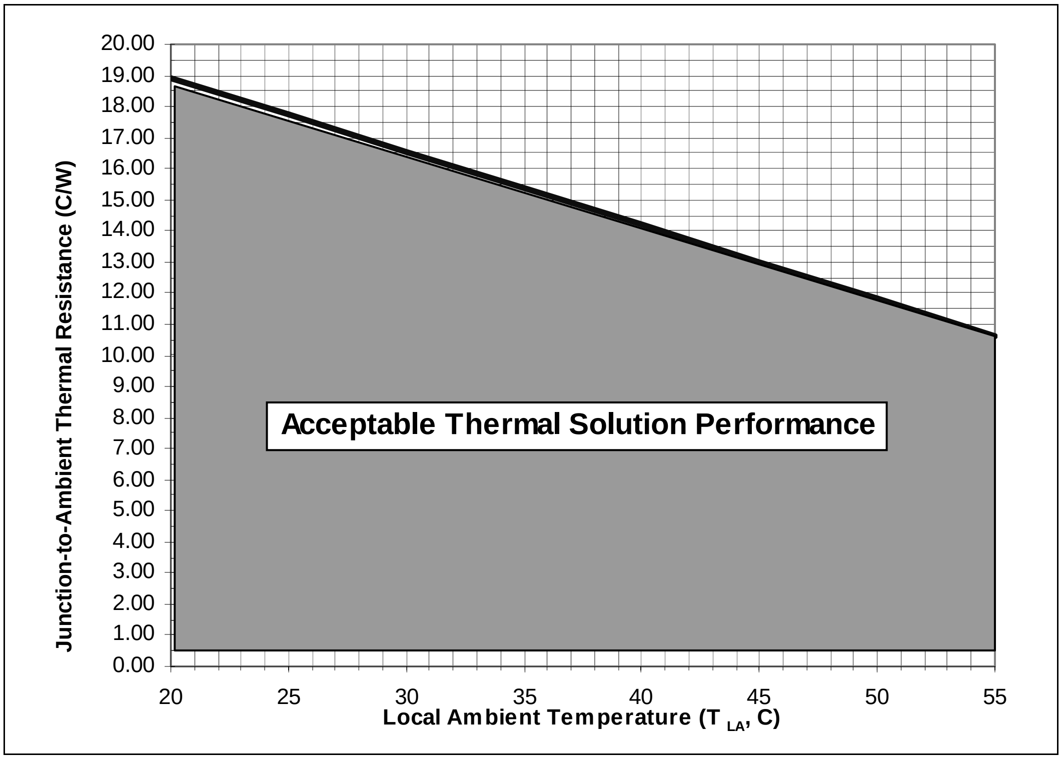


Figure 4. Thermal Resistances for Various Operating Temperatures (400 MHz Processor)



2.2.4 Recommended Heat Sink Design

Two heat sinks have been designed that meet the required thermal performance for a minimum ambient temperature of 50° C. The heat sinks shown in Figure 4 and Figure 7 were optimized using computational fluid dynamic (CFD) and thermal modeling software. The heat sink designs are optimized for a minimum airflow of 200 LFM, as measured 1 inch upstream from the processor.

The geometry is also optimized for high volume manufacturing. All designs can be manufactured using extrusion and folded fin heat sink manufacturing technologies. A list of enabled heat sink vendors is provided in Section 3.0. The information provided in this document is for reference only and additional validation must be performed prior to implementing the designs into final production.

Due to the low thermal design power (TDP) associated with these Ultra-Low Voltage Celeron processors (0.13 µ), a natural convection thermal solution is practical. Particularly the Ultra-Low Voltage Celeron 400 MHz processor (0.13 µ) is suitable for use in environments where natural convection cooling is needed. Equation 2 shows the required thermal solution performance needed for the 400 MHz processor. The thermal resistance values are reasonable to achieve with a relatively small aluminum heat sink and proper chassis venting. At lower local ambient temperatures, it is even more feasible to cool the ULV 400 MHz processor with natural convection. Likewise, at lower ambient temperatures it may be possible to cool the 650 MHz processor with natural convection cooling as well.

It is important to note that a suitable heat sink is always needed to cool the processors. Natural convection cooling refers to the absence of forced airflow from a fan and instead requires adequate system venting to allow for a natural convection effect. It is the responsibility of the OEM to design their system with a suitable heat sink and venting for natural convection cooled systems.

2.2.4.1 Heat Sink Design Option 1

Heat sink option 1 has been designed to maximize the available space within the keep out zone. The geometry of the heat sink is shown in Figure 5. Thermal modeling and verification tests indicate that this heat sink has a junction-to-ambient thermal resistance less than 6.02° C/W with an airflow velocity of 75 LFM. The thermal resistance at other airflow rates is shown in Figure 6. This heat sink must be oriented in a specific direction relative to the processor keep out zone and airflow. In order to use this design, the processor must be placed on the PCB in an orientation so the heat sink fins will be parallel to the airflow. Figure 7 illustrates the orientation of the heat sink relative to the processor, keep out zone, and airflow. A top view of the heat sink on the processor assembly is shown.

With no forced airflow (natural convection) the heat sink thermal resistance is 9.8° C/W. Therefore this heat sink is suitable for natural convection cooling with the 400 MHz processor (at 50° C the required thermal performance is 11.82° C/W, refer to Equation 2). The heat sink is not suitable for natural convection with the 650 MHz processor (the required thermal resistance is 6.02° C/W, refer to Equation 1). It is important to note that the thermal design team must ensure that proper venting is included in the natural convection system. Likewise it is important for the design team to verify that the heat sink is still suitable in the overall system design. A system-level thermal analysis is required to confirm that this heat sink is suitable for natural convection cooling when all system components and operating conditions are considered. The orientation of the heat sink is not critical in a natural convection system, so the heat sink can be placed in the assembly in any orientation without affecting the heat sink performance.

Figure 5. Heat Sink Design Option 1

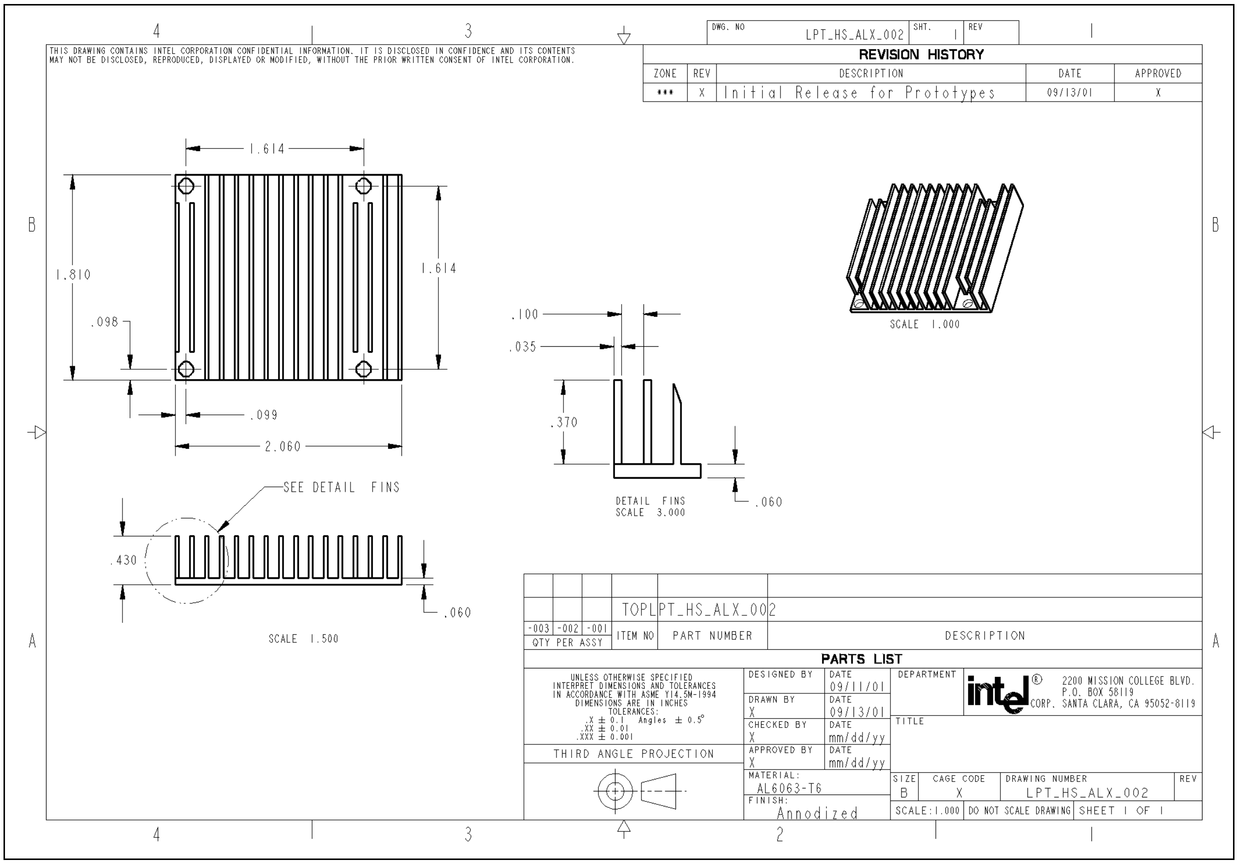


Figure 6. Heat Sink Option 1 Thermal Performance Curve

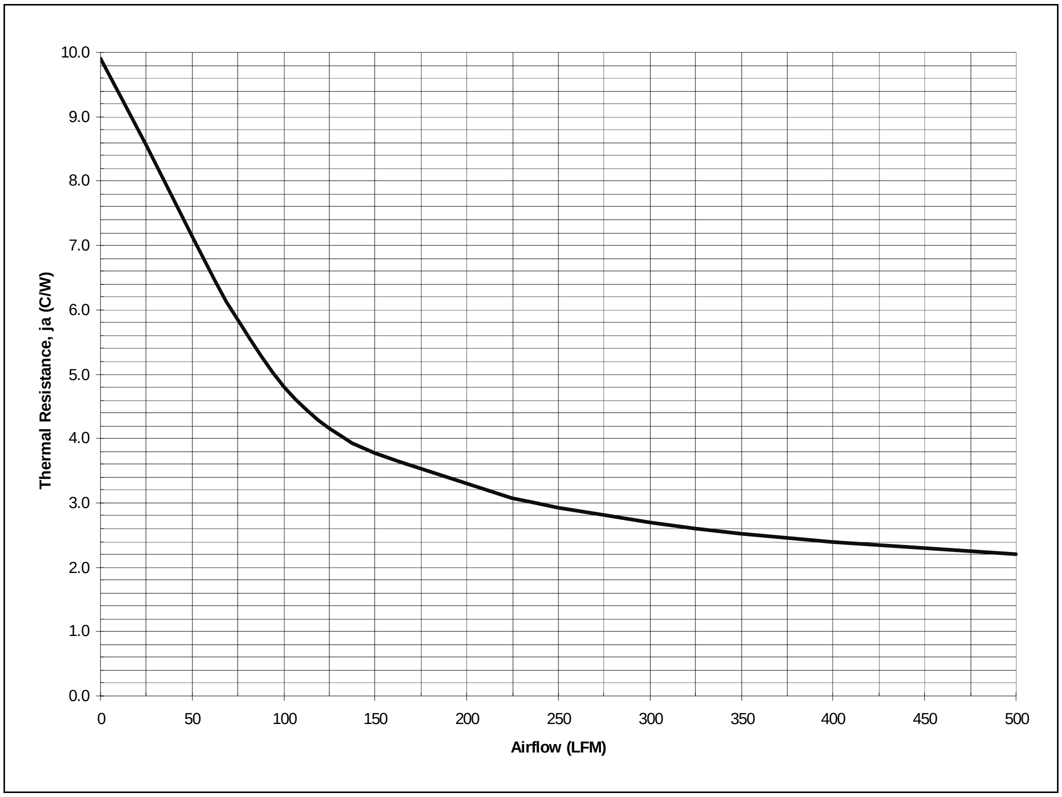
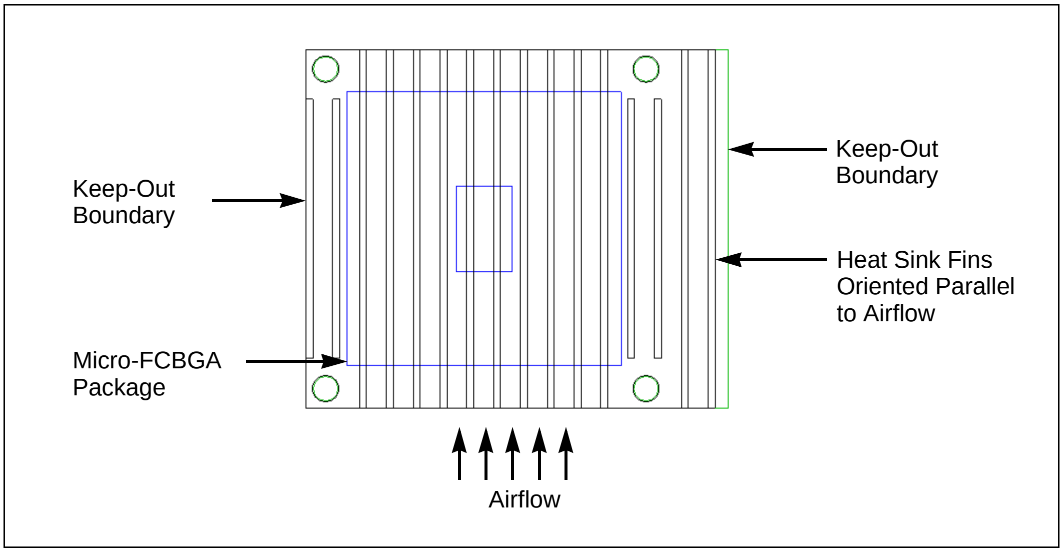


Figure 7. Heat Sink Option 1 Acceptable Orientation to the Processor & Airflow



2.2.4.2 Heat Sink Design Option 2

Heat sink option 2 has been optimized to be the smallest size possible within the keep out zone and using the standard mounting hole pattern. The geometry of the heat sink is shown in Figure 8. Thermal modeling and verification tests indicate that this heat sink has a junction-to-ambient thermal resistance of less than 6.02° C/W at 100 LFM. The thermal resistance at other airflow rates is shown in Figure 9. This heat sink is symmetrical and can be placed in any orientation relative to the processor. However, extreme care must be taken to make sure that the heat sink is assembled to the PCB with the fins parallel to the airflow. Figure 10 illustrates the orientation of the heat sink relative to the processor, keep out zone, and airflow. A top view of the heat sink on the processor assembly is shown.

With no forced airflow (natural convection) the heat sink thermal resistance is 10.6° C/W. Therefore this heat sink is suitable for natural convection cooling with the 400 MHz processor (at 50° C the required thermal performance is 11.82° C/W, refer to Equation 2). The heat sink is not suitable for natural convection with the 650 MHz processor (the required thermal resistance is 6.02° C/W, refer to Equation 1). It is important to note that the thermal design team must ensure proper venting is included in the natural convection system. Likewise it is important for the design team to verify that the heat sink is still suitable in the overall system design. A system-level thermal analysis is required to confirm that this heat sink is suitable for natural convection cooling when all system components and operating conditions are considered. The orientation of the heat sink is not critical in a natural convection system, so the heat sink can be placed in the assembly in any orientation without affecting the heat sink performance.

Figure 8. Heat Sink Design Option 2

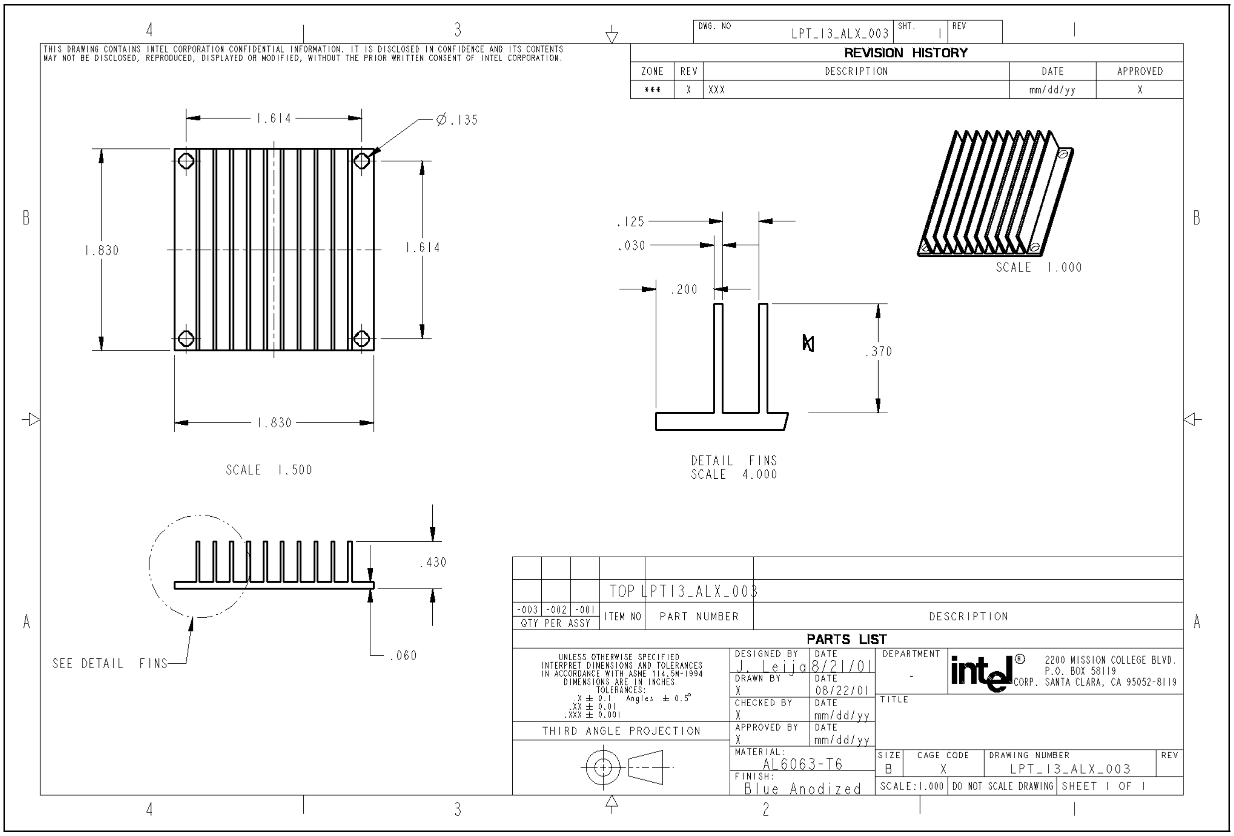


Figure 9. Heat Sink Option 2 Thermal Performance Curve

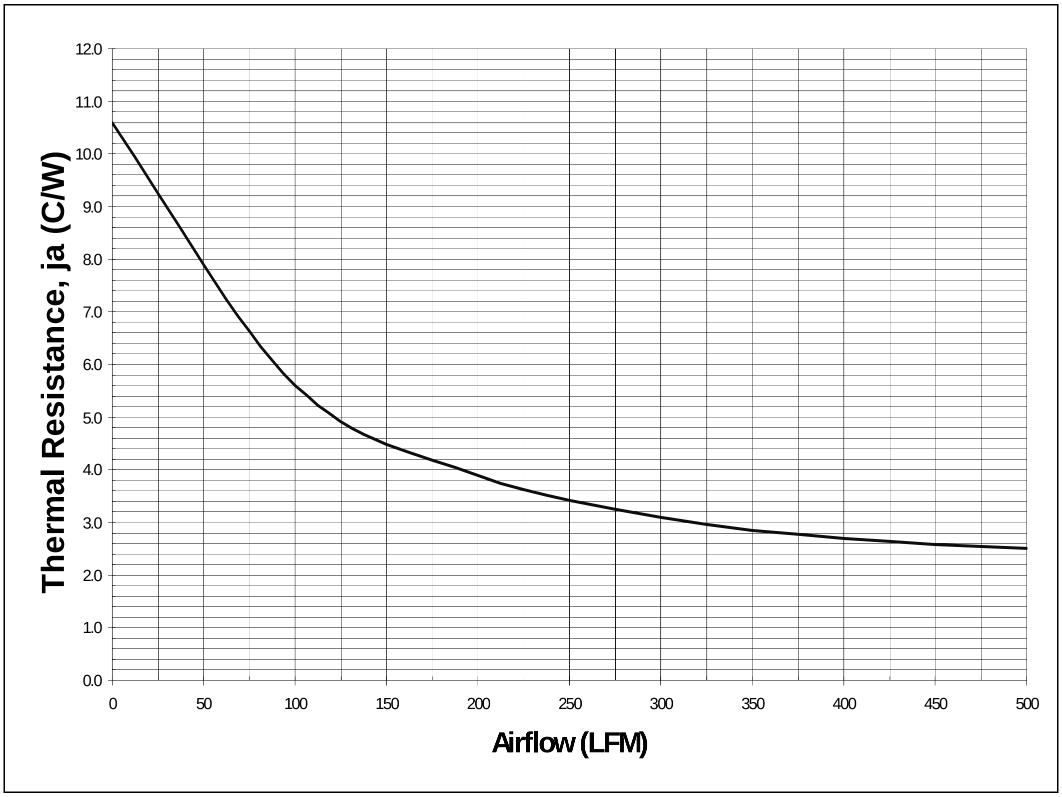
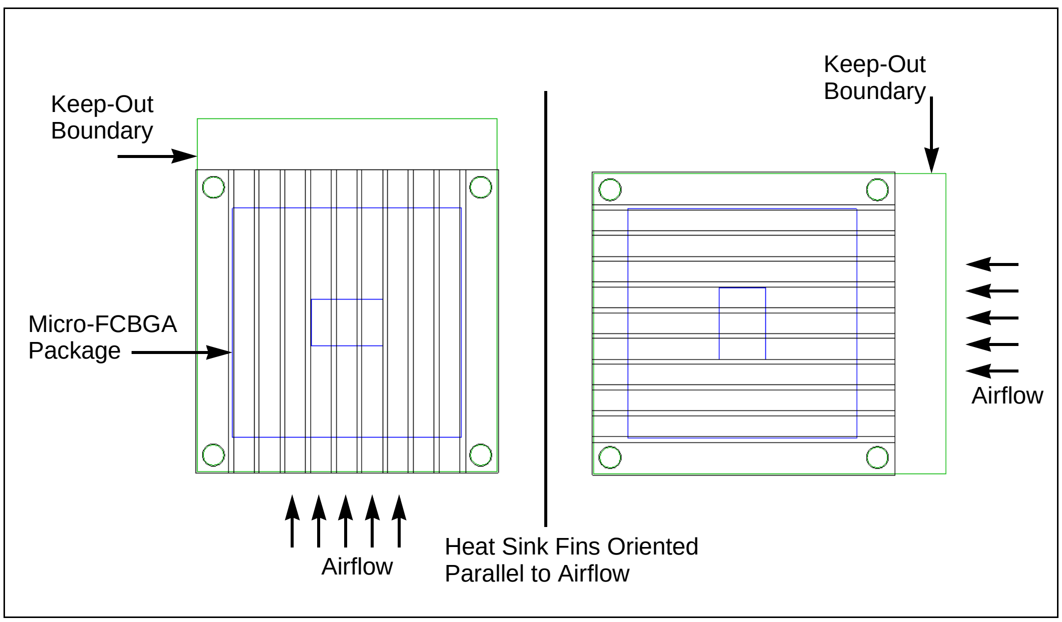


Figure 10. Heat Sink Option 2 Acceptable Orientations to the Processor & Airflow



2.2.4.3 Alternative Heat Sink Designs

Additional thermal solutions are available for the Ultra-Low Voltage Intel® Celeron® processor in the Micro FC-BGA package for other form factors. A summary of thermal solutions can be obtained in the *Thermal Design Guide for Intel® Processors in the BGA2 and Micro FC-BGA Packages for Embedded Application*s (Document # 273716).

In addition, an active heat sink with a fan mounted directly on top is available from Tyco Electronics Corporation. The active heat sink mounts using the same hole pattern described in Figure 2. This solution is suitable for laboratory testing, or other applications where system airflow is not available. The Tyco part number is PN8-1542007-5.

2.2.5 Recommended Thermal Interface Material

It is important to understand and consider the impact the interface between the processor and heat sink base has on the overall thermal solution. Specifically, the bond line thickness, interface area, and interface material thermal conductivity must be managed to optimize the thermal solution.

It is critical that the thickness of the thermal interface material, commonly referred to as the bond line thickness, be minimized. A large gap between the heat sink base and processor yields a greater thermal resistance. The thickness of the gap is determined by the flatness of both the heat sink base and the processor, plus the thickness of the thermal interface material, and the clamping force applied by the heat sink attachment mechanism. To ensure proper and consistent thermal performance, the TIM and application process must be properly designed.

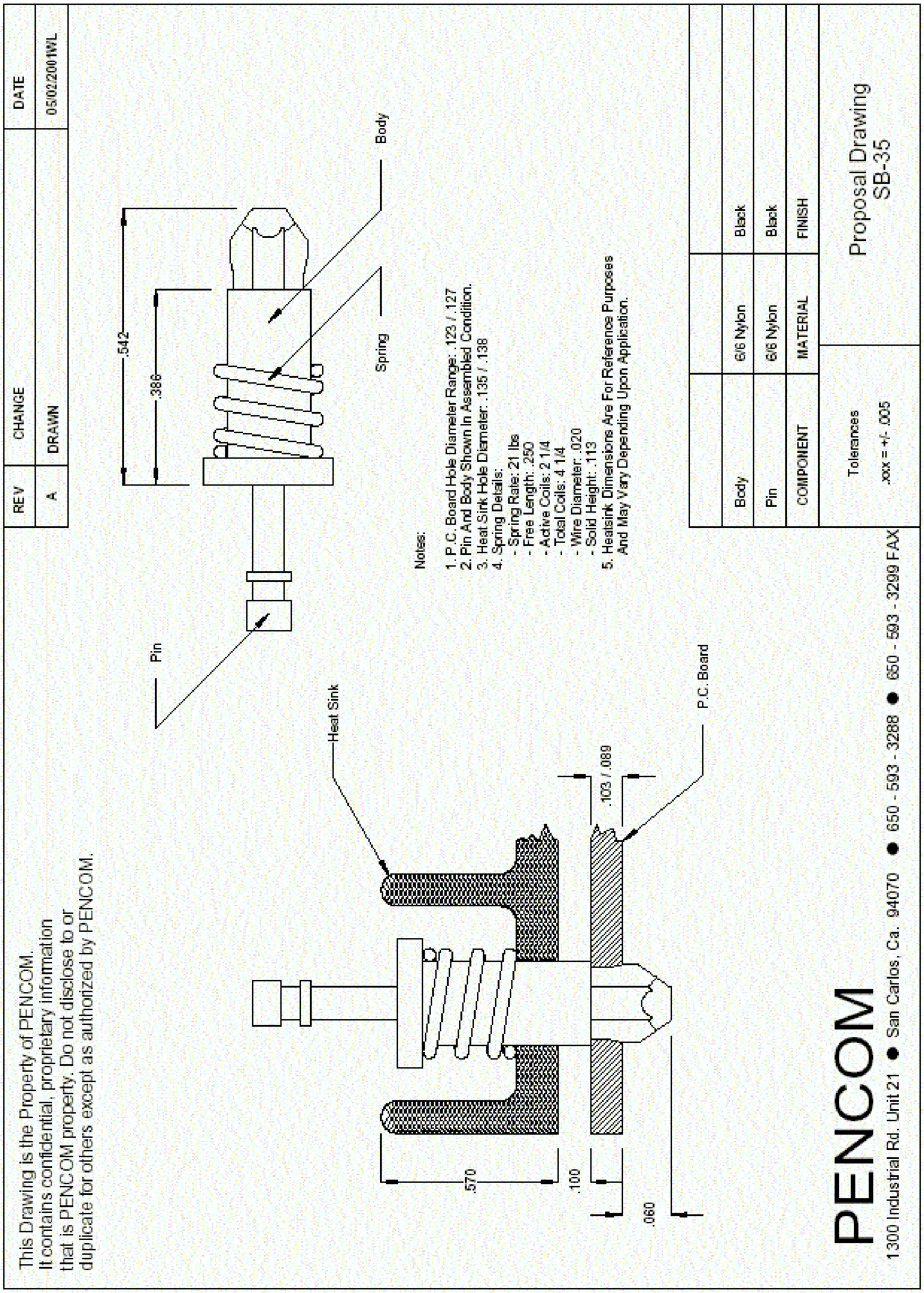
The heat sink solutions were optimized using a high-performance phase change thermal interface material (TIM) with low thermal impedance. The heat sinks were prototyped and verified using Chomerics T725* phase change interface pads. Vendor information for this material is provided in Section 3.0. Alternative materials can be used at the user’s discretion. The entire heat sink assembly including the heat sink, attachment mechanisms, and interface material must be validated together for specific applications.

2.2.6 Recommended Heat Sink Attachment Method

The heat sinks are designed to secure to the PCB with four spring-loaded fasteners placed at each corner of the base. The spring-loaded fasteners apply force to the heat sink base to maintain a desired pressure on the thermal interface material between the processor and the heat sink, and to hold the heat sink in place during dynamic loading. Figure 11 shows an example of a spring-loaded fastener that meets the pressure requirements of the processor. A mounting fastener is available that interfaces with both a 0.063- and 0.093-inch thick PCB.

The heat sink designs were prototyped and verified using the PENCOM* fastener for the 0.093-inch thick PCB. Vendor information for this fastener is provided in Section 3.0.

Figure 11. Heat Sink Mounting Fastener Assembly



Drawing used with permission from PENCOM

3.0 Vendor List

Table 3 provides a vendor list as a service to our customers for reference only. The inclusion of this list should not be considered a recommendation or product endorsement by Intel® Corporation.

Table 3. Heat Sink Mounting Fastener Assembly

Aluminum Extruded Heat Sink - Option 1 (Reference No. EID-LPT13-ALX-003)	
Peninsula Components (PENCOM) 1300 Pioneer Street, Suite E Brea, CA 92821	Contact: Steve Blank (562) 694-4477
Aluminum Extruded Heat Sink – Option 2 (Reference No. EID-LPT15-ALX-002)	
Peninsula Components (PENCOM) 1300 Pioneer Street, Suite E Brea, CA 92821	Contact: Steve Blank (562) 694-4477
Heat Sink Mounting Fasteners (PENCOM P/N: PL1664-65)	
Peninsula Components (PENCOM) 1300 Pioneer Street, Suite E Brea, CA 92821	Contact: Steve Blank (562) 694-4477
Thermal Interface Material (Chomerics Material No. Thermflow* T725)	
Parker Hannifin Corporation (Chomerics Division) 842 E. Fairway Drive Orange, CA 92866	Contact: John Kefeyan (714) 639-6079
Active Heat Sink (Tyco P/N: 8-1542007-5)	
Tyco Electronics Corporation 62 Nahatan Street Norwood, MA 02062	J. Sawich (800) 468-2023

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